At the Edge of the Universe:
Latest Results from the Deepest Astronomical Surveys
ASP Conference Series, Vol. 380, 2007
José Afonso, Henry C. Ferguson, Bahram Mobasher, and Ray Norris, eds.

The Evolution of Radio Galaxies: Their Infancy

Pedro Augusto

Grupo de Astronomia, Universidade da Madeira, Caminho da Penteada, 9000-390 Funchal, Portugal

Abstract. In order to understand the origin and evolution of radio galaxies, searches for the youngest such sources have been conducted. Compact-medium symmetric objects (CSO-MSOs) are thought to be the earliest stages of radio sources, with possible ages of $< 10^3$ yrs for CSOs (< 1 kpc in size) and 10^4–10^5 yrs for MSOs (1–15 kpc). From a literature selection in heterogeneous surveys, we have established a sample of 37 confirmed CSOs: the typical CSO resides on a $z < 0.5$ galaxy, has a flat radio spectrum ($\alpha_{thin} < 0.5$; $S_\nu \propto \nu^{-\alpha}$), is < 0.3 kpc in size, has an arm length ratio ≤ 2, and well-aligned ($\theta \leq 20°$) opposite lobes with a flux density ratio ≤ 10. With the objective of improving the statistics of large CSOs (0.3–1 kpc) and flat-spectrum MSOs (with only three cases known), we have built a sample of 157 flat-spectrum radio sources resolved with the VLA-A at 8.4 GHz. We here sum up the status of our study of this sample, which includes the confirmation of, at least, two new flat-spectrum MSOs (two other sources lack redshifts for their final classification as either flat-spectrum MSOs or large CSOs), virtually doubling the number of such sources known.

This paper is organized in a question-answer style. Each Section corresponds to a question with the answer given in the corresponding text body.

What is a CSO or an MSO?

Morphologically, a compact-medium symmetric object (CSO-MSO) resembles classical Fanaroff & Riley (1974) type II radio galaxies (FRIIs) of which the archetype is Cygnus A. FRIIs contain prominent 'hotspots' where two opposed jets, that originate at a central supermassive black hole, are thought to violently collide with the ISM/IGM (reaching $\sim$0.1–1 Mpc from the active galactic centre). CSO/MSOs, however, can be up to 10^6 times smaller than FRIIs (projected[1] linear sizes < 15 kpc). Operationally, the divide between CSOs and MSOs is at a size of 1 kpc: the smaller sources are CSOs (< 1 kpc) while the larger ones are MSOs (1–15 kpc).

[1]Since they are thought to be oriented close to the plane of the sky, as FRI/FRIIs are, the projected linear size should be a good measure of their actual physical sizes.

What are the properties of a typical CSO?

A total of 37 CSOs were confirmed from the literature beyond any reasonable doubt[2] (Augusto et al. 2006). Although obviously not forming a statistically complete sample they might, nevertheless, shed light into the "typical" CSO:

- the host is a galaxy (85% of CSOs; 73% complete);
- cosmological neighborhood, $z < 0.5$ (68%; 68%);
- flat-spectrum, $\alpha_{thin} < 0.5$, $S_\nu \propto \nu^{-\alpha}$ (56%; 86%);
- weak nucleus (70%; 78%);
- lobe flux density ratio < 10 (73%; 100%);
- arm ratio < 5 (all; 78%);
- well aligned, $\theta < 20°$ (76%; 78%);
- linear projected size (median) is $0.14^{+0.07}_{-0.05}$ kpc.

What is the role of CSO/MSOs in radio source evolution?

Unfortunately, due to poor statistics (which our work will, hopefully, substantially improve) this is still not clear. There is consensus, however, on CSOs being young radio sources ($< 10^3$ yrs). Evidence amounts from kinematics of hotspot motions in ten cases which give CSO ages on ∼300–2000 yrs (e.g. Augusto et al. 2006).

Given their morphology and age, it is quite tempting to assume that CSO/MSOs are the progenitors of the large FRIIs. However, this is far from conclusive. A good portion of CSOs could rather be the precursors of Fanaroff & Riley (1974) type I radio galaxies (FRIs): these contain a bright core; the brightest regions of the jets are much closer to the nucleus than in FRIIs — the jets do not end in 'hotspots' but rather "fizz out" discretely. Or, even, many could be 'reborn' radio sources with several 'burst' episodes in their past revealed by relic radio emission seen around them (in scales much larger than ∼1 kpc) — e.g. Augusto et al. (2006).

What is the currently favoured evolutionary scheme?

Judging from the current statistics (i.e. lack of flat-spectrum MSOs and of large CSOs), the favoured model is self-similar evolution, i.e., CSOs grow to become steep spectrum MSOs on the way to their final FRI/FRII stage. For example, Augusto, Wilkinson, & Browne (1998) place an upper limit on the abundance

[2] Confirmation of a CSO/MSO comes from at least one of the following as regards the source structure: i) two hotspots in opposed motion (shown kinematically); ii) on a two-component source: edge brightness clearly seen in both components; iii) on a multi-component source: a central component is proven as the core (from multi-frequency high resolution observations).

of large CSOs/flat-spectrum MSOs: their abundance is, at least, three times smaller than the one of small CSOs as found on VLBI surveys. However, the total number of flat-spectrum MSOs and large CSOs is too small to be more conclusive on this result.

So, the literature contains 37 confirmed CSOs. And how many MSOs?

In short: not too many (tens?). The bulk have steep spectrum properties. They are included, by obvious reasons, in the type of sources called Compact Steep Spectrum sources (CSSs; $\alpha_{thin} > 0.5$), possibly constituting about one-third of these — they stand out for being symmetric. Unfortunately, a proper compilation and rigorous structure confirmation is still lacking for steep spectrum MSOs.

What about flat-spectrum MSOs? Do they exist?

Yes, of course they do. However, they have oddly been overlooked, so far. We did recover three from the literature. But this is still a very small number. We must dramatically increase the statistics on these objects. Here we virtually reach the double of the previously known number (reaching five to six MSOs).

Why are flat-spectrum MSOs so relevant?

The main interest is statistical:

1. if they are abundant, the favoured evolutionary scheme would be: CSO → flat-spectrum MSO → FRI/FRII; this is called non-self similar evolution (e.g. Tschager et al. 2000) since in this case the lobes of CSOs will not expand until a very late stage — after the MSO phase, possibly when 10^7–10^8 yrs old, much closer to the FRI/FRII 10^9–10^{10} yrs ages;

2. if they are not abundant, the favoured evolution would be: CSO → steep spectrum MSO → FRI/FRII; this evolution is self-similar with the lobes expanding as the source grows.

What else is missing?

Large CSOs. Indeed, out of the 37 known cases only four fall in the size range 0.3–1 kpc. The remaining have sizes on 0.01–0.3 kpc.

Our work aims also at finding many more large CSOs than are currently known. Improving their statistics, together with the one of flat-spectrum MSOs, is vital for the investigation of which evolutionary scenario is preferred (if any): self-similar or non-self-similar.

How do *WE* plan to find many more large CSOs/flat-spectrum MSOs?

Starting from a parent sample of 1743 sources with flat radio spectrum ($\alpha_{1.4}^{4.85} < 0.5$; $S_\nu \propto \nu^{-\alpha}$), $S_{8.4\,\mathrm{GHz}} > 100$ mJy and out of the galactic plane ($\left|b^{II}\right| > 10°$) — Augusto et al. (2006) — we selected a sample of 157 sources resolved with the VLA-A at 8.4 GHz; this implies that we selected sources with structure consistent with a size $> 0\farcs1$. We now plan to follow up all strong candidates to CSO/MSOs at radio and optical wavelengths.

Some preliminary results from our study of the 157-source sample:

- 61 sources were immediately rejected;
- nine CSO/MSOs have been "rediscovered";
- two new flat-spectrum MSOs were found, both ∼14 kpc in size (J0751+826 and J1454+299);
- one new CSO/MSO (lacks redshift for final classification): 4C+66.09;
- one new flat-spectrum MSO (lacks redshift for confirmation);
- 83 sources need further radio data (multi-frequency and high resolution) for the first stage of inspection.

What is the status in the study of the 157-source sample?

We have obtained VLA, MERLIN, and VLBI data for most of the yet-to-classify 83 sources. We are now processing these data, combining all maps and information in order to confirm or rule out more CSO/MSO candidates. A paper with the next set of results should come out in MNRAS in 2007.

References

Augusto, P., Wilkinson, P. N., Browne, I. W. A. 1998, MNRAS, 299, 1159
Augusto, P., Gonzalez-Serrano, J. I., Perez-Fournon, I., Wilkinson, P. N. 2006, MNRAS, 368, 1411
Fanaroff, B. L., Riley, J. M. 1974, MNRAS, 167, P31
Tschager, W., Schilizzi, R. T., Rottgering, H. J. A., Snellen, I. A. G., Miley, G. K. 2000, A&A, 360, 887